TECHNICAL NOTE

Michael W. Warren,[1] *Ph.D.; Kendra R. Smith,*[1] *M.F.S.; Phoebe R. Stubblefield,*[1] *M.A.; Shuala S. Martin,*[1] *B.A.; and Heather A. Walsh-Haney,*[1] *B.A.*

Use of Radiographic Atlases in a Mass Fatality*

REFERENCE: Warren MW, Smith KR, Stubblefield PR, Martin SS, Walsh-Haney HA. Use of radiographic atlases in a mass fatality. J Forensic Sci 1999;45:467–470.

ABSTRACT: In May and June of 1996, a forensic anthropology team from the C.A. Pound Human Identification Laboratory at the University of Florida identified 9 of 10 juveniles from the crash of ValuJet 592. The team relied primarily on a radiographic atlas developed and used by clinical practitioners to determine skeletal age. Postmortem radiographs of the juvenile victims were compared with radiographic standards to determine skeletal age. Skeletal age was then compared to a passenger list indicating the sex, weight, height, and chronological age of each individual. Tentative identifications based on the atlas method were organized into an exclusion matrix. Final identifications were based on this assessment in conjunction with other anthropological data such as appearance and fusion of ossification centers and estimation of stature.

KEYWORDS: forensic science, forensic anthropology, mass fatalities, radiographic atlas, ValuJet, identification, juveniles

The identification of victims from mass fatalities resulting from high-speed aircraft accidents is difficult because remains are incinerated and extremely fragmented (1,2). In such cases, identification is typically based upon fingerprints, dentition, DNA analysis, and/or comparison of antemortem and postmortem radiographs (3–9). Although these methods of identification are well-represented in the scientific literature (3–9), no current literature specifically refers to the use of radiographic atlases in the identification of subadult victims of mass fatalities.

A forensic anthropology team from the University of Florida's C.A. Pound Human Identification Laboratory consulted in the identification of the juvenile victims from the ValuJet Flight 592 disaster. Although several methods were employed, the radiographic atlas method of determining skeletal age proved to be the most useful. Gruelich and Pyle's *Radiographic Atlas of Skeletal Development of the Hand and Wrist* (10) was of particular importance because these elements were well-represented among the recovered remains, but radiographic atlases of the knee (11), and the foot and ankle (12) were also used. Skeletal age, determined using the atlases, was compared to known chronological age and other antemortem information derived from biological profiles provided by family members. A total of nine juveniles were identified within a three week interval. Of these, the atlas technique was essential in eight identifications. A ninth was identified using other anthropological methods (i.e., epiphyseal union and stature estimation).

Materials and Methods

The remains recovered from the crash site were severely fragmented. Cranial fragments and teeth were rarely recovered. Juvenile remains were separated from adult remains by examination of soft tissue morphology or radiographic identification of immature bones and joints. Juvenile remains were then radiographed in the position demonstrated in the respective atlas, on unscreened Kodak EM-1 diagnostic mammography film.

Accurate antemortem information was obtained through questionnaires completed by surviving family members which provided the identification team with specific information on exact birth dates, weights, and statures. In some cases, photographs of the decedents were available. This information provided evidence that none of the juveniles on the aircraft exhibited considerable growth retardation or acceleration.

Because hands were well represented among the remains, most of our determinations of skeletal age were based on comparisons of postmortem radiographs to standards in the Greulich and Pyle atlas (see Figs. 1a through 3b). When a knee, or foot and ankle was recovered, we utilized respectively the atlases of Pyle and Hoerr (11) and Hoerr et al. (12). Skeletal age was then compared to a passenger list database that included the chronological age of record for each individual. Tentative identifications based on the atlas method were organized into a simple matrix. Few complete long bones were associated with joints that had atlas referents. When unassociated limbs were recovered, skeletal age was estimated on the basis of long bone diaphyseal length (13) or from the appearance and fusion of various ossification centers (14). This information was used in conjunction with the atlas results. Other anthropological data, such as estimated stature, were also used to support final identifications.

Results

Nine of the juvenile passengers from the crash of ValuJet 592 were identified using anthropological methods. Of the hands recovered ($N = 9$, including one pair of antimeres), seven were associated with the six youngest individuals on the plane, based on

[1] Visiting assistant professor, graduate assistants, and lab technician, respectively, Department of Anthropology, C.A. Pound Human Identification Laboratory, University of Florida.

* This manuscript was presented in a poster session at the 49th annual meeting of the American Academy of Forensic Sciences in New York.

Received 3 June 1998; and in revised form 16 Oct. 1998; accepted 5 Jan 1999.

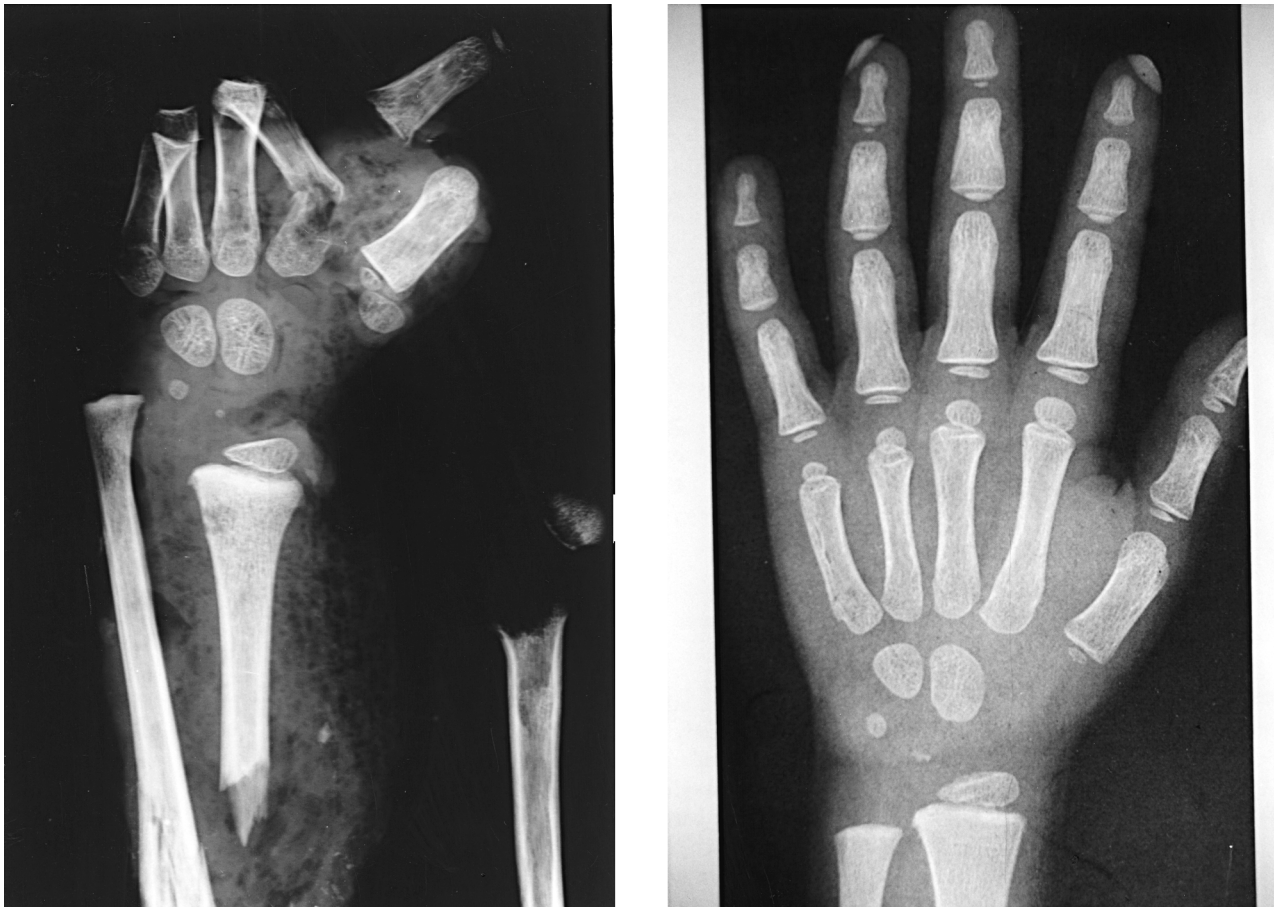

FIG. 1—*(a) Left hand of passenger 1 (male; chronological age 3 years 4 months); (b) Gruelich & Pyle male standard 10 (skeletal age 3 years).*

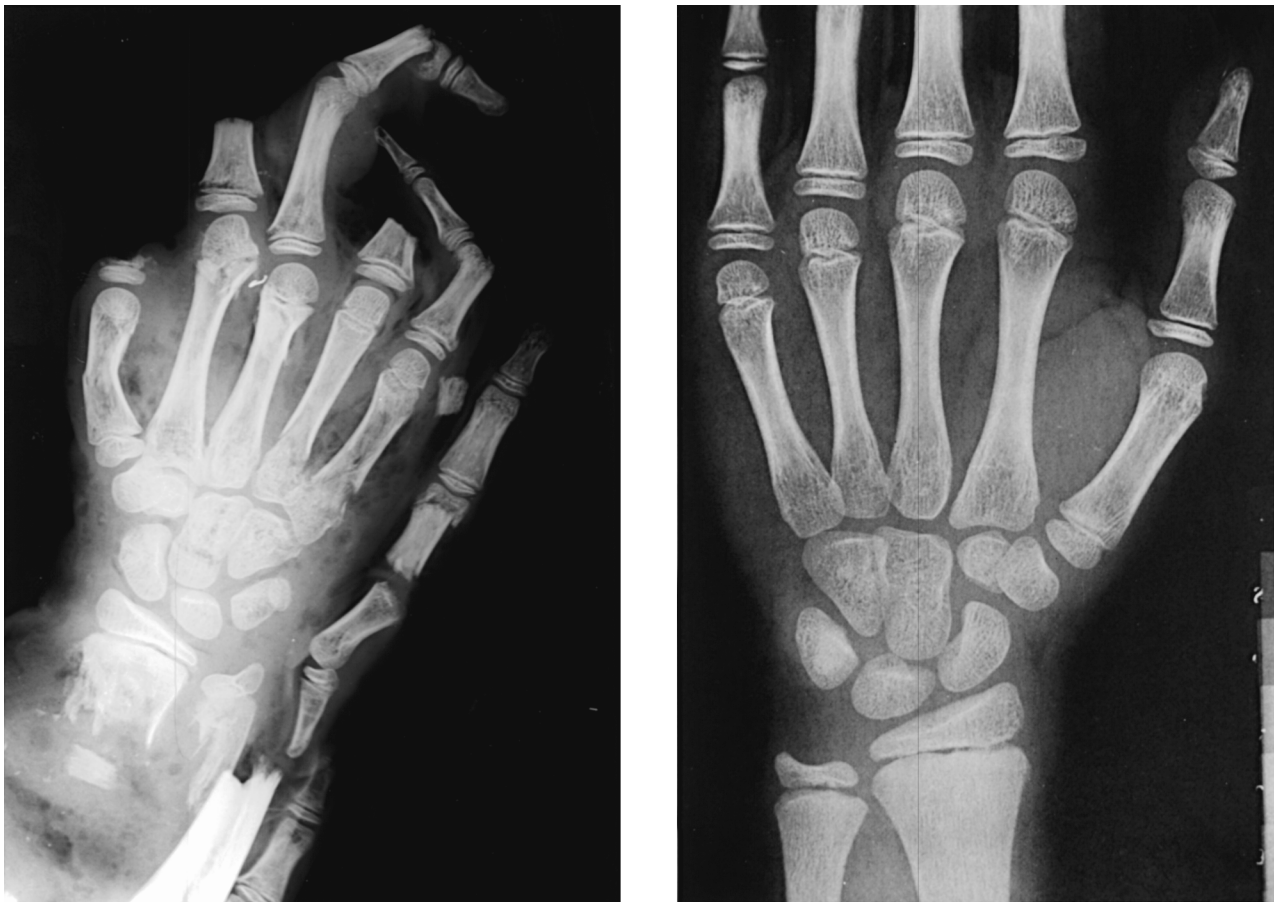

FIG. 3—*(a) Right hand of passenger 5 (female; chronological age 8 years 8 months); (b) Gruelich & Pyle female standard 17 (skeletal age 8 years 10 months).*

TABLE 1—*Exclusion matrix for the hand.*

	Sex	Age	Left	Right	Skeletal Age
Passenger 1	M	3 years 4 months	Male std #10		3 years
Passenger 2	M	5 years 2 months	Male std # 13		4 years 3 months
Passenger 3	F	6 years 8 months	Female std #15		6 years 10 months
Passenger 4	F	7 years 6 months		Female std #16	7 years 10 months
Passenger 5	F	8 years 8 months	Female std #17	Female std #17	8 years 10 months
Passenger 6	F	11 years 11 months	Female std #20		12 years
Passenger 7	F	13 years 6 months	Remains identified by other anthropological methods		
Passenger 8	F	14 years 3 months		Fingerprint ID	n/a
Passenger 9	M	15 years 2 months		Fingerprint ID	n/a
Passenger 10	M	15 years 2 months			14 years

skeletal ages derived from the Gruelich and Pyle atlas (Table 1). The remaining hands represented two passengers identified by fingerprints.

Knees ($N = 6$) and feet ($N = 4$), with one exception, were identified only in individuals who had also been identified from a hand. The three youngest and the two oldest individuals were also identified from knees, while only passengers 1, 3, and 6 were also identified from feet. Passenger #10 was identified solely from a knee.

While the radiographic atlas method was instrumental in identifying eight of ten passengers, a ninth individual (passenger #7) was identified by determination of skeletal age based on appearance and fusion of ossification centers in the shoulder and arm. Stature estimates, based on humerus length, were also important.

Discussion

The demographics of the passenger list enabled the team to rely more heavily on the atlas than might normally be possible.

FIG. 2—(a) *Left hand of passenger 2 (female; chronological age 5 years 2 months); (b) Gruelich & Pyle male standard 13 (skeletal age 4 years 6 months).*

The team was able to identify the majority of the children because of the spacing of birth dates and the separation between the ages of males and females in the group. Of the ten juveniles under the age of sixteen, the two youngest and two oldest were males (Table 1). The slower skeletal maturation of males enabled the younger two to be easily differentiated from the females. The level of skeletal development demonstrated by male standard 13 (see Table 1, Passenger #2) corresponds closely to the development illustrated in female standard 11. However, female standard 11 represents typical development in females at age three years and six months while the youngest female on the passenger list was six years and eight months. Therefore the remains showing such a level of development could only belong to male passenger #2. The level of skeletal maturity in the two older males may have corresponded well with at least the oldest female; however, the males were six inches taller than the tallest female. Therefore, large size and increased robusticity combined with unfused epiphyses distinguished the oldest males from all others.

Radiographic methods of determining level of skeletal maturity were originally developed for comparing skeletal age with chronological age in children suspected of exhibiting abnormal growth patterns. Proper assessment of skeletal age contributes to accurate diagnosis, assists in the timing of corrective orthopedic surgery, and aids in prediction of adult height.

Both quantitative and normative methods have been developed for determining stages of skeletal development. Quantitative methods, such as the Tanner-Whitehouse (13), Oxford (14), or Fels (15) methods assign scores based on morphological "indicator grades." Skeletal age is determined by the sum of scores derived from assessment of each specific ossification center. The Fels method also provides confidence intervals for the median age.

Radiographic atlases offer a set of standard radiographs that represent a modal or "typical" level of skeletal maturity in the extremities at a given chronological age. The Greulich and Pyle radiographic atlas of the hand and wrist (10) is widely used in clinical radiology because vital organs are spared X-ray exposure. In addition, the hand and wrist are easily accessible, several bones are present in a small area, and the hand can consistently be placed in a standard position with little overlap of skeletal elements. The atlases for the foot and ankle, (16) and knee (17) are difficult to obtain and are generally considered less reliable for assessment of overall skeletal maturity than those of the hand and wrist.

In the case of the ValuJet crash, the extreme fragmentary condition of the remains precluded the use of quantitative methods because they require the presence of specific centers or evaluate centers from multiple body regions. Instead, the atlas was preferred for initial evaluation of skeletal age of the ValuJet victims because it allowed relatively rapid assessment and because at least one hand was recovered from six of the ten juvenile victims.

Every mass fatality presents a unique challenge for identification specialists. The nature of the disaster, the demographic composition of the victims, and the degree of trauma inflicted on the bodies dictate which methods will be effective. The remains of the victims of the ValuJet 592 tragedy were highly fragmented; the anthropologists were asked to assist only in the identification of a specific subset of the victims (i.e., the juveniles); and the chronological age and the distribution of the sex of the victims was fortuitous. Given these circumstances, we feel that the atlas method was a most effective and efficient technique for identifying the juvenile victims.

Acknowledgments

First and foremost, we owe our deepest gratitude to the late Dr. William R. Maples, our mentor and teacher. Dr. Maples was the primary anthropology consultant in the crash of Valujet 592, and it was through his gracious permission that we, his students, were able to participate in this investigation. We also gratefully acknowledge Dr. Roger Mittleman, Chief Medical Examiner for the Metro-Dade Office of the Medical Examiner, who granted permission for this publication. We appreciate the assistance and hospitality of Scott Hanks, the associate medical examiners, and the staff of the Metro-Dade office. We also thank Dr. Anthony B. Falsetti for sharing his expertise in mass fatalities.

Finally, express our sympathy to the families and friends of the victims of the ValuJet tragedy.

References

1. Hinkes MJ. The role of forensic anthropology in mass disaster resolution. Aviat Space Environ Med July 1989;A60–A63.
2. Hellerich U, Pollak S. Airplane crash: traumatic findings in the cases of extreme body disintegration. Am J Forensic Med Path 1995;16(4):320–4.
3. Hill IR. Dental identification in fatal aircraft accidents. Aviat Space Environ Med 1980;51(9):1021–5.
4. Flichtenstein JE, Madewell JE, McMeekin RR, Feigin DS, Wolcott JH. Role of radiology in aviation accident investigation. Aviat Space Environ Med Sept 1980;1004–14.
5. Mulligan ME, McCarthy MJ, Wippold FJ, Lichtenstein JE, Wagner GN. Radiologic evaluation of mass casualty victims: lessons from the Gander, Newfoundland, accident. Radiology 1988;168:229–33.
6. Kahana T, Ravioli JA, Urroz CL, Hiss J. Radiographic identification of fragmentary human remains from a mass disaster. Am J Forensic Med Path 1997;18(1):40–4.
7. Wagner GN, Froede RC. Medicolegal investigations of mass disasters. In: Spitz WU, editor. Medicolegal investigation of death: guidelines for the application of pathology to crime investigation 3rd Edition. Springfield: Charles C Thomas, 1993;567–84.
8. Sanger RG, Wilson GA. Survey of North American air carriers regarding protocol for dental identification of in-flight personnel. J Forensic Sci 1982;27(1):19–22.
9. VandenBos A. Mass identification: a multidisciplinary operation. Am J Forensic Med Path 1980;1(3):265–70.
10. Gruelich WW, Pyle SI. Radiographic atlas of the skeletal development of the hand and wrist. Cambridge University Press, 1959.
11. Flecker H. Time of appearance and fusion of ossification centers as observed by roentgenographic methods. Am J Roentgenology and Radium Therapy 1942;47(1):97–159.
12. Hoffman JM. Age estimation from diaphyseal lengths: two months to twelve years. J Forensic Sci 1979;24(2):461–6.
13. Tanner TM, Whitehouse RH, Cameron N, Marshall WA, Healy MJR, Goldstein H. Assessment of skeletal maturity and prediction of adult height (TW2 method). London: Academic Press, 1983.
14. Acheson RM. A method of assessing skeletal maturity from radiographs. Report from the Oxford Child Health Survey. J Anat 1954;88:498–508.
15. Roche AF, Chumlea WC, Thissen D. Assessing the skeletal maturity of the hand-wrist: fels method. Springfield: Charles C Thomas, 1988.
16. Hoerr NL, Pyle SI, Francis CC. Radiographic atlas of the foot and ankle. Springfield: Charles C Thomas 1962.
17. Pyle SI, Hoerr NL. Radiographic atlas of skeletal development of the knee. Springfield: Charles C Thomas 1955.

Additional information and reprint requests:
Heather A. Walsh-Haney, B.A.
C.A. Pound Human Identification Laboratory
P.O. Box 112545
University of Florida
Gainesville, FL 32611